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TRANSPORT OF COAL-TAR DERIVATIVES IN THE PRAIRIE DU CHIEN-JORDAN AQUIFER, ST. LOUIS PARK, MINNESOTA

A Project Proposal

by the

U.S. Geological Survey
St. Paul, Minnesota

November 1980

PROPOSED
SUBJECT TO REVISION

US EPA RECORDS CENTER REGION 5
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INTRODUCTION

Operation of a coal-tar distillation and wood-preserving plant during 1918-72 in St. Louis Park, a suburb of Minneapolis, Minnesota, resulted in serious contamination of ground water. The severity of the pollution, and the progress made by local, State, and Federal agencies in defining and resolving the technical, management, and legal issues involved, have made this particular problem highly visible. The Minnesota Pollution Control Agency and Region V of the U.S. Environmental Protection Agency have identified the contamination in St. Louis Park as the most significant single example of ground-water pollution identified to date within their jurisdiction.

In July 1978, the U.S. Geological Survey, in cooperation with the Minnesota Department of Health, began a two-year project to obtain a detailed understanding of the transport of coal-tar derivatives through the ground-water system in the St. Louis Park area. Hult and Schoenberg (1980) present a summary of the data obtained during the first year of the study and preliminary conceptual models of the mechanisms and pathways of contaminant transport. Hult (1981a) interprets these and additional data in greater detail, and presents the results of preliminary analytical and computer modeling of transport in the Prairie du Chien-Jordan aquifer. Hult (1981b) evaluates the effect of multiaquifer wells on the spread of contaminants between aquifers.

As stated in the project proposal for the first two-year project (December 1978, p. 2):

> "The problem is complex... The first two-year study (MN 79-061) will provide valuable insight into the problem and will aid decisions on probable continuation of the project for at least two more years. Development and application of a calibrated ground-water transport model to evaluate the possible effects of remedial actions proposed by State and local agencies will require extension of this project."

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The new two-year project now being proposed is in agreement with the timing and purpose of the project foreseen in 1978 and cited in the previous paragraph. The major effort is to help resolve this particular contamination problem. However, contamination of ground water by toxic organic compounds is a National problem. Research by the U.S. Geological Survey to obtain a detailed understanding of the St. Louis Park problem may have significant transfer value to similar problems elsewhere.

> "Because of intense local concern, considerable Federal interest, complexity of the problem, and difficulty of effective remedial action, it is anticipated that continued funding will be available. The approach to the problem must therefore balance the immediate needs of the cooperators with the longer-term requirements of a more definitive study." (1978 project proposal, p. 4).

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THE PROBLEM

The problem of most immediate concern is the presence of toxic organic compounds in water withdrawn from some municipal wells in the area. When the first municipal well was drilled in 1932, the Prairie du Chien-Jordan aquifer, the region's major ground-water resource, contained water with a coal-tar taste at least 3,500 feet from the plant site. During 1978-80, use of five more St. Louis Park municipal wells completed in this aquifer was discontinued because the wells yielded water containing trace amounts of coal-tar compounds, including benzo(a)pyrene, a carcinogen. Contaminants have moved at least 2 miles northeast and southeast of the site. Each of the five bedrock aquifers in the metropolitan area underlies the site, and each may have been affected to some degree by the contaminants.

The complicated ground-water hydrology, the diverse chemical and physical properties of coal-tar constituents, and the length of time the contaminants have been moving through the ground-water system, have combined to produce a complex distribution of contaminants.

Individual coal-tar compounds differ widely in toxicity and chemical and physical properties. For example, phenol is about 10 million times more soluble in water than benzo(a)pyrene. Differences in solubility and sorbtion characteristics cause large variations in the proportion of each chemical that is dissolved into the ground water, remains in a mixture of liquid hydrocarbons, or is sorbed onto geologic materials. The proportions change with chemical concentration, in space, and with time.

Figure 1 shows the conceptual model of the introduction and transport of contaminants through the ground-water system. Coal-tar derivatives reached the water table by percolation through the unsaturated zone and at ponds that received surface runoff and process water from the plant (fig. 1). The highest concentrations of contaminants are in the drift beneath and near the site. Parts of this drift contain an undissolved, liquid mixture of many individual coal-tar compounds. In June 1980, a sample of this liquid from a monitoring well completed in the drift 50 feet below the water table contained 97,000 mg/L total organic carbon. The hydrocarbon fluid has moved vertically downward relative to the direction of ground-water flow because it is denser than water. It is moving more slowly than the ground water because it is more viscous.

Ground water entering the area of the plant site through the drift is contaminated by partial solution of the hydrocarbon fluids and by release of compounds sorbed on the drift materials. The contaminated water moves laterally to the east and southeast, and downward into the Platteville aquifer. Water in the drift 4,000 feet from the site contains less than 10 mg/L dissolved organic carbon, but has a distinct "chemical" odor, and contains a large proportion of coal-tar compounds of high solubility in water relative to compounds of low solubility.

It seems that some contaminant compounds moving through the drift are being degraded to other organic compounds and to methane. However, the rates of degradation, the compounds being degraded and the nature of intermediate degradation products are unknown.

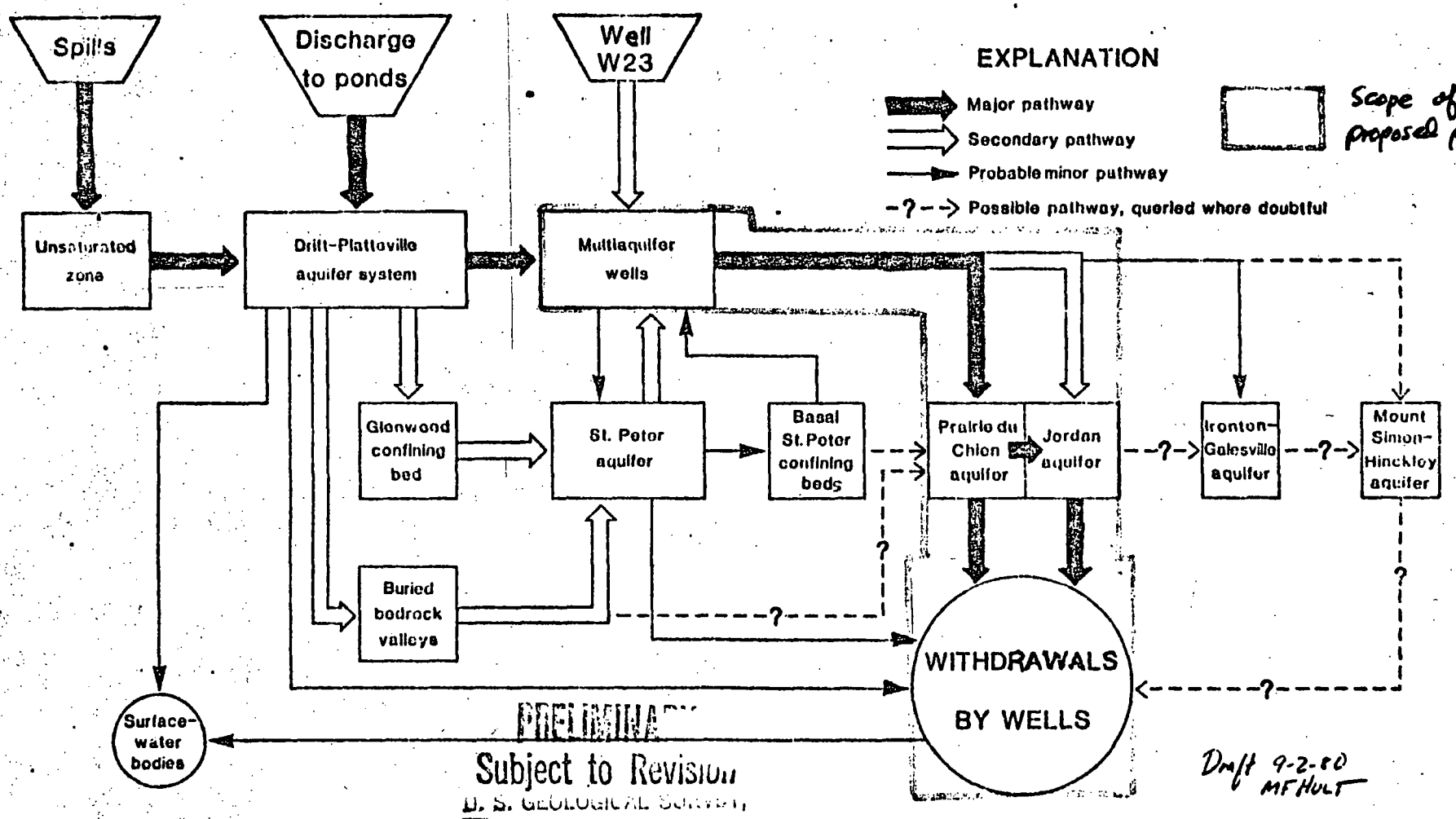

Figure 1.—Flow chart showing conceptual model of introduction and transport of coal-tar derivatives through the ground-water system, St. Louis Park area, Minnesota and scope of proposed project (modified from Hult, 1980a)

Contaminants entered the uppermost bedrock aquifer, the Platteville aquifer, directly from the drift and have moved at least 7,000 feet from the site. The contaminants reached deeper bedrock aquifers, primarily the Prairie du Chien-Jordan aquifer, through wells that hydraulically connect the aquifers (fig. 1). Coal-tar compounds have moved to a depth of at least 650 feet in the bore of a multiaquifer well 4,000 feet from the site. Locally, the contaminants have reached the St. Peter aquifer through the Glenwood confining bed and(or) through bedrock valleys where the confining bed has been removed by erosion (fig. 1). In addition, coal-tar has entered the bedrock-aquifer system, possibly from a spill, through a well on the site that was drilled in 1917 to a depth of 909 feet (well W23; fig. 1).

The bedrock ground-water flow system is continually adjusting to hydraulic stresses such as ground-water withdrawals and flow through wells that connect more than one aquifer. As these stresses change, the direction and rate of contaminant transport changes. Because the upper part of the Prairie du Chien-Jordan aquifer is a carbonate rock having fracture and solution-channel permeability and low effective porosity, contaminants can move rapidly through this aquifer. Consequently, the concentration and composition of contaminants in water pumped from individual industrial and municipal wells completed in the Prairie du Chien-Jordan aquifer fluctuates with time (fig. 2).

About 80 percent of ground-water withdrawals in the St. Louis Park area are from the Prairie du Chien-Jordan aquifer (Hult, 1981a). All eight of the municipal wells that have been shown to be contaminated are completed in this aquifer. Use of six of these wells has been discontinued. Therefore, the project being proposed would focus specifically on the Prairie du Chien-Jordan aquifer.

OBJECTIVES

The goal of this and the previous report is to obtain a detailed understanding of the transport of coal-tar derivatives through ground water in the St. Louis Park area. This understanding will be used to test management strategies suggested by the cooperators or their consultants. The research may also have considerable transfer value to ground-water contamination problems elsewhere in the nation.

The specific objectives of the proposed study are to:

1. Develop the ability to predict contaminant movement in the Prairie du Chien-Jordan aquifer.
2. Provide for consultation with the U.S. Geological Survey by the U.S. Environmental Protection Agency, the cooperators, and their consultants.
3. Provide for continued geophysical logging and evaluation of multiaquifer wells as they are located in the field.
4. Preserve continuity in the collection of time-series water-level and pumpage data from all aquifers.

5. Continue collection of chemical data in the Prairie du Chien-Jordan aquifer needed to define the distribution of contaminants.

6. Collect time-series chemical data needed to attempt calibration of the transport model.

7. Provide continuing support for related, but separately-funded, basic and applied research by the U.S. Geological Survey.

A major emphasis in the proposed project is the development of a method for evaluating the effectiveness of measures taken to minimize both the concentration of coal-tar derivatives in municipal wells in the area, and the continued spread of contaminants in the Prairie du Chien-Jordan aquifer. Hult (1981a) has shown that manipulation of withdrawals from industrial and municipal wells, in conjunction with a continued effort to locate, evaluate, and seal multiaquifer wells permitting contaminated water to flow into the aquifer, may be effective in minimizing the concentration of contaminants reaching municipal wells. Preliminary solute-transport computer models of the aquifer that have been developed to date have proven to be a useful tool in evaluating the problem. The proposed project focuses on refining this tool to better reflect actual hydrogeologic conditions, and to use it to evaluate the effectiveness of present and future management ~~studies~~ strategies.

SCOPE

The proposed project would focus on the Prairie du Chien-Jordan aquifer (fig. 1).

Multiaquifer wells are the major pathways of contaminant transport to the Prairie du Chien-Jordan aquifer identified to date (Hult, 1981a; 1981b). Continuing evaluation of multiaquifer wells, in conjunction with the well-abandonment program of the MDH, is within the scope of the proposed project. Reconstruction of multiaquifer wells as monitoring wells would require additional funding.

Evaluation of other pathways of contaminant transport to the aquifer (fig. 1) will depend on previously collected data. Coal tar entered the Prairie du Chien-Jordan aquifer through a deep well on the site (well W23; "Hinckley well on the site"). The coal tar in and around the well may be a continuing source of contaminants to the aquifer (Hult, 1978; 1979a; 1979b; 1981a; 1981b; Hult and Schoenberg, 1980). Specific steps needed to evaluate and minimize impact of this source have been suggested to the Minnesota Department of Health. These steps would require additional funding.

Contaminants may be entering the Prairie du Chien-Jordan from the overlying St. Peter aquifer (fig. 1). The mass of contaminants which has entered the aquifer through this pathway appears to be small compared to that which entered through multiaquifer wells (Hult 1981a). Installation of additional monitoring wells would be needed to further test this hypothesis.

Management strategies aimed at minimizing the impact of the contaminants are summarized in table 1. Each of the three user alternatives have been implemented or are being evaluated by the city of St. Louis Park. The quality of water withdrawn from municipal wells is being monitored by the city and the Minnesota Department of Health. Pilot studies by the city and their consultants have shown that organic contaminants can be partly removed by treatment with activated carbon. The city has increased their reliance on deeper wells, completed in the Mount Simon-Hinckley aquifer, and are evaluating the costs and desirability of deepening existing wells, drilling new, deeper wells, and(or) obtaining water from the city of Minneapolis.

Continued detailed evaluation of the drift, Platteville, St. Peter, Ironton-Galesville, and Mount Simon-Hinckley aquifers is beyond the scope of the proposed project. The scope of the proposed project could be expanded to include additional work if funding becomes available. The relationship between past projects, the proposed project, and possible future projects is shown in table 2.

Table 1.--Summary of management strategies to minimize the impact of ground-water contaminants (modified from Hult, 1981a)

1. USER ALTERNATIVES

   a. Monitor the quality of water at the well head. If unacceptable quality,

   b. Treat, or

   c. Develop alternative supplies.

2. AQUIFER MANAGEMENT

   a. Prevent or reduce movement of contaminants into the aquifer of concern. For example, locate and seal multiaquifer wells that permit contaminated water to flow into the Prairie du Chien-Jordan aquifer.

   b. Control the movement of contaminants within the aquifer of concern so that the concentration of contaminants at each withdrawal well does not exceed acceptable limits. In the Prairie du Chien-Jordan, this might be accomplished by manipulating pumpage from municipal and industrial wells, and by pumping wells installed for the purpose of changing hydraulic gradients.

Table 1.--Summary of management strategies to minimize the impact of ground-water contaminants (modified from Hult, 1981a)--Continued

3. SOURCE MANAGEMENT

a. Intercept contamination leaving the source volume in the drift with withdrawal wells, treat (if necessary), and reinject or discharge.

b. Immobilize the contaminants in the source volume either physically with hydraulic or physical barriers, or chemically by reducing contaminant solubility.

c. Convert contaminant compounds in the source to other compounds that are less toxic by encouraging in-situ degradation by anerobic bacteria or by providing oxygen for aerobic degradation.

d. Remove (partly) the source by excavation and pumpout wells.

Table 2.--Relationship of proposed project to past and possible future projects

USGS project	Dates	Principal objectives	Related activities by other agencies	USGS publications
Project	July 1978-June 1979	Develop a detailed understanding of the transport of coal-tar derivatives through aquifers in the St. Louis Park area.	Well abandonment program by MDH	Hult and Schoenberg, 1980
MN-79-061	July 1979-Sept. 1980			Hult, 1981a; 1981b
Proposed project	Oct. 1980-Sept. 1982	Develop the ability to predict contaminant transport in the Prairie du Chien-Jordan aquifer.	Design of proposed remedial action by MDH consultant	1982
Possible future projects	Oct. 1981-Sept. 1982	Continue collection of time-series data in all aquifers. If additional funding becomes available, and contingent on availability of project chief for project work, refine understanding of transport processes in the drift, Platteville, St. Peter, Ironton-Galesville, and(or) Mount Simon-Hinckley aquifers.	Implementation of remedial action by State and local agencies	
	Oct. 1982-Sept. 1983	Attempt calibration of transport models based on four years of time-series chemical data and response of the ground-water system to remedial action. Design a long-term monitoring strategy to monitor and evaluate the effectiveness of remedial measures.		

The proposed project focuses on developing the ability to predict contaminant movement within the Prairie du Chien-Jordan aquifer in order to assess the effectiveness of the aquifer management strategies indicated in table 1. The Minnesota Department of Health began a program of well abandonment in February 1979, based on information provided by the U.S. Geological Survey. This program seems to have been very effective in reducing the amount of contaminants entering the Prairie du Chien-Jordan aquifer. Because contaminants can move rapidly through the Prairie du Chien part of the Prairie du Chien-Jordan, manipulating pumpage from wells may be an effective way of reducing the contaminant concentration at any given well, and of preventing the further spread of the contaminants. Figure 2 shows changes in the concentration of individual coal-tar compounds in St. Louis Park municipal well 4 as a function of pumpage from municipal well 6. Well 4 was pumped only for the purpose of obtaining samples. Both wells are completed in the Prairie du Chien-Jordan aquifer; no other nearby wells were known to have been pumping during the period indicated.

These data support the tentative conclusion that manipulating pumpage may be a cost-effective way of reducing contaminant concentrations at individual withdrawal wells. However, additional time-series data on contaminant concentration, pumpage, and water levels are needed to test whether the correlation between pumpage and chemical concentration is coincidental, or whether there is a causal relationship.

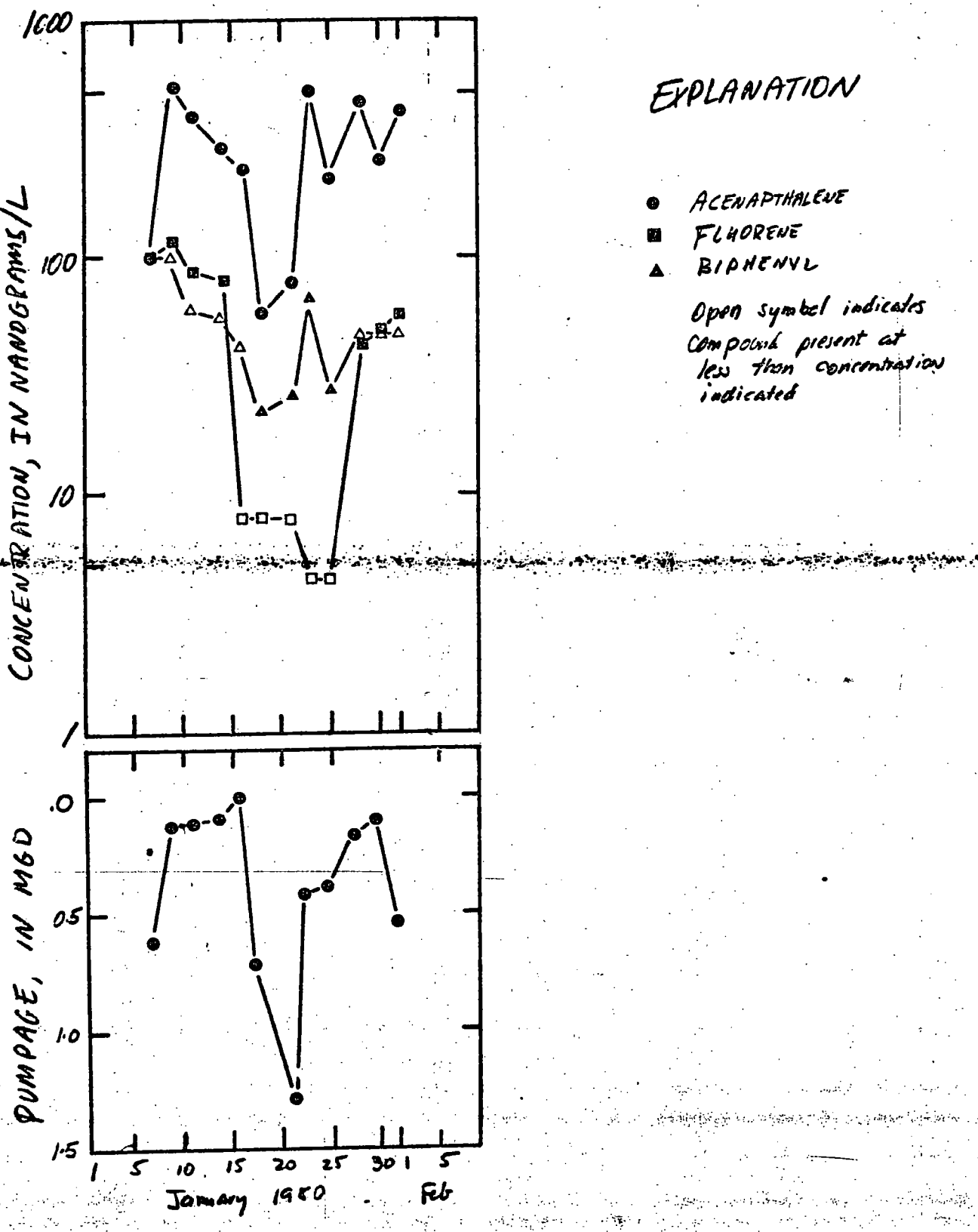

Figure 2.— Changes in water quality in St Louis Park Municipal well 4 as a function of pumpage from well 6, January 1980. Both wells are completed in the Prairie du Chien–Jordan aquifer. (From HULT, 1981a)

APPROACH

The principal activities needed to meet the objectives are (1) refinement and maintenance of the network used to monitor water levels, water quality, and pumpage, (2) a mass sampling of wells in the Prairie du Chien-Jordan aquifer to determine the areal extent of measureable contamination, (3) additional coring, sampling, and chemical analyses to better define the composition and physical characteristics of the contaminant sources in the drift and well W23, (4) continued work on identifying, locating, testing, and sealing or reconstructing multiaquifer wells; this work will be done in cooperation with the Minnesota Department of Health, and (5) refinement of the transport model of the Prairie du Chien-Jordan aquifer to reflect actual hydrogeologic boundaries and hydraulic and chemical stresses.

It is also anticipated that pumping tests will be conducted in the drift and Platteville in order to better evaluate aquifer characteristics. The Minnesota Pollution Control Agency will obtain necessary permits (if any) for discharge of contaminated water.

As funding, the availability of wells, and time permit, attempts will be made to obtain additional time-series data on water quality in the Prairie du Chien-Jordan, and to continue monitoring the quality in other aquifers.

The Regional Water-Quality Specialist will be consulted in order to develop an adequate quality-assurance program. This is needed to establish the validity of the chemical analyses from the various laboratories involved. It is anticipated that continued support will be available from the U.S. Geological Survey Central Laboratory system in developing a quality-assurance program, and in chemical characterization of the contaminants. A complete description of the quality-assurance program will be developed as part of the proposed project.

Mass Sampling of Prairie du Chien-Jordan Aquifer

The purpose of the mass sampling of the Prairie du Chien-Jordan aquifer is to obtain more complete information on the distribution of individual organic and inorganic constituents within the aquifer at a single point in time. This sampling effort, as with past efforts, will be restricted to wells that are available for sampling. Many wells in the area are used for air conditioning and irrigation and may not be available for sampling during winter months. An attempt will be made to coordinate this sampling effort with the ongoing monitoring by the MDH. Specifically, the MDH could help in making arrangements for sampling of wells that may otherwise not be available. It would also be highly desirable for the MDH to analyze the concentration of PAH compounds by HPLC in samples taken at the same time as those collected by the U.S. Geological Survey for analysis by an EPA contractor. Because the MDH intends to continue monitoring, this approach will require no additional laboratory work by the MDH. It will, however, help in the evaluation of the compatibility and reproducibility of analytical results from the various

laboratories involved. Likely, it will also identify acid, base, and low-molecular weight neutal compounds that may be of concern to regulatory agencies.

Tasks:
1. Compile existing information on water quality and wells.
2. Identify areas where additional wells are needed.
3. Compile list of candidate wells for sampling.
4. Field locate new wells and make necessary arrangements.
5. Sample approximately 40 wells within 2- to 3-week period.

Refinement and Maintenance of Monitoring Network

Water quality, water levels, and(or) pumpage from about 300 wells in the St. Louis Park area were measured as part of the previous project. This network will be reevaluated, modified, and maintained as necessary to best meet the data needs of the proposed project and future activities.

It is anticipated that about 6 additional recorders will be installed to monitor pumpage and water levels at major pumping centers. The frequency of measurement will be reduced at most wells in the drift and Platteville. Attempts will continue to locate additional wells, in aquifers, and in areas where data are sparse.

Continued Chemical Characterization of the Contaminant Source in the Drift and Well W23

Cores will be obtained from at least two additional locations in the most highly contaminated volume of drift, and some previously collected cores, ~~and~~ will be chemically analyzed for individual organic ~~compoudns~~ compounds. The samples will be analyzed by an EPA contractor, and by the U.S. Geological Survey. (and from the coal tar in well 23. These samples,)

Evaluation of Multiaquifer Wells

As additional wells are located in the field, the U.S. Geological Survey will log the wells geophysically, and measure water levels and vertical flow within the well bore (if any). The Minnesota Department of Health will provide for removal of obstrucution in the well bores (if any), collect and analyze water samples, log with downhole television camera, and permanently seal or reconstruct as needed and as funding permits.

Model Development

The purpose of the ground-water solute transport model is to (1) provide a framework for quantitative accounting of the major processes in and properties of the ground-water system that govern the transport of contaminants, and (2) provide a tool that can be used in quantitative and qualitative evaluations of the effectiveness of ongoing and possible future remedial actions aimed at reducing the severity of contamination in the Prairie du Chien-Jordan aquifer.

Tasks:

1. Expand and refine present two-dimensional transport model (Konikow and Broedehoeft) to better reflect actual conditions. Test parameter sensitivities.
2. Using SWIP, incorporate separate layers for Prairie du Chien and Jordan, and realistic boundary conditions. Attempt headmatching (steady-state and transient).

2a. If necessary to reduce computer costs, construct and use three-dimensional flow model (Trescott) to evaluate flow problem. Transfer refinements to SWIP and retest.

3. Using SWIP, add simplified history of contaminant introduction to evaluate transport rates and directions, parameter sensitivities, and uncertainties caused by probable presence of unlocated multiaquifer wells.
4. Using SWIP and measured distribution of contaminants, evaluate effect of manipulating pumpage, including municipal wells, industrial wells, and hypothetical barrier wells.
5. Using SWIP, and as time and time-series data permit, attempt calibration of transient transport of selected contaminant compounds.

Model data needs and source of information

1. Aquifer and confining bed geometry - from Hult and Schoenberg, 1980; Guswa, 1981.
2. Aquifer and confining bed hydraulic properties - from previous pumping and laboratory tests in St. Louis Park and elsewhere in the Twin Cities basin - Guswa 1981, and ATES project.
3. Hydrogeologic boundaries - from Guswa, 1981 (Twin Cities project).
4. Hydraulic head - from Hult and Schoenberg, 1980; Guswa, 1981, and from monitoring network refined and operated for the current project.
5. Adsorbtion isotherms - from batch experiments to be conducted by the University of Minnesota for phenol, naphthalene, and acenapthene.
6. Ground-water withdrawals - compiled for previous project (061) and from monitoring network refined and operated for current project.
7. Hydraulic effect of multiaquifer wells - from Hult, 1981a; 1981b; and from measurements made for the current project.
8. Chemical effects of multiaquifer wells - from Hult and Schoenberg, 1980a; Hult, 1981a; 1981b; and from measurements made for the current project.
9. Present distribution of selected contaminant compounds - from Hult, 1981a, and from chemical mass measurements made for the current project.
10. Time-series data on concentration of selected contaminant compounds - from Hult, 1981a. Some additional measurements may be made for the current project.

TIME AND COST SCHEDULE

The costs for this proposed project (Federal FY 81 and 82) will be shared by the Minnesota Departement of Health, City of St. Louis Park, Minnesota Pollution Control Agency, U.S. Environmental Protection Agency, and U.S. Geological Survey. Development of the computer model of the Prairie du Chien-Jordan aquifer will be completed during FY 81. A report will be prepared, reviewed, and published during FY 82. The Minnesota Department of Health will collect and analyze samples from municipal wells, provide down-hole television camera surveys, and prepare selected wells for geophysical logging in the amount of $36,000 in lieu of funds that will be matched by the Geological Survey. The City of St. Louis Park will assist in monitoring pumpage, water levels, and water quality in municipal wells, and will provide landscaping of monitoring-well sites in the amount of $10,000 in lieu of funds that will be matched by the Geological Survey. Proposed funding is as follows.

St. Louis Park Proposed Funding for FY 81

	Cash	Services	USGS match	WOTSC[1]	DOTSC[2]	Net cash
EPA	$50,000	$ ---	$ ---	$ 7,250	$12,750	$30,000
SLP	5,000	10,000	15,000	2,700	5,100	12,200
MPCA	14,000[3]	---	14,000	2,520	7,140	18,340
MDH	5,000	36,000	41,000	7,380	11,730	26,890
Total	74,000	46,000	70,000	19,850	36,720	87,430

1 EPA - 14.5 percent; all others at 9 percent.
2 25.5 percent of all cash and matching; 0 percent on direct services.
3 Funds may come from either MPCA or MDH.

Itemized expenditures for FY 1981

Direct services	$ 46,000
Salaries	48,430
Travel	1,500
Supplies	2,500
Equipment	6,500
Vehicles	2,800
Computer	10,700
Laboratory	5,000
Drilling	7,000
Analytical services (University of Minnesota)	3,000
DOTSC	36,720
WOTSC	19,850
Total	190,000

Proposed Funding for FY 82--Report processing and publication

Hydrologist (1/2 time)	$ 14,000
Printing and reproduction	2,500
DOTSC	6,250
WOTSC	2,250
Total	$ 25,000

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